A Quality Function Deployment (QFD) for Electric Snowmobile – Phase 1

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Abstract

Indiana University - Purdue University Indianapolis (IUPUI) mechanical engineering students have come together to design, build, and operate a zero emissions clean snowmobile. The objective for the designed snowmobile is to pass technical inspection and compete in all events of the SAE 2016 Clean Snowmobile Challenge in order to establish a baseline of improvement for future competitions.

In order to determine the primary areas (events) to focus on, a quality function deployment (QFD) was developed. From the development of the QFD, it was shown that range, weight, and draw bar pull were the three events that required the most emphasis. Therefore, the design decisions made to the stock snowmobile were made to improve these three event categories. Some of these improvements include battery and motor selection. With these two modifications, it is predicted that the designed snowmobile will be able to complete the established objective of competing in each category in order to generate a baseline of results for future competitions.

Table 1: Desired Outcomes for SAE 2016 Zero Emission Clean Snowmobile Competition

Event	Target
MSRP	$18000
Range	32.2 km
Draw Bar Pull	1.4 kN
Noise	65 dB
Drivability & Handling	60 s
Acceleration Plus Load	20 s
Cold Start	PASS
Weight	2.2 kN

Introduction

Efficient zero emission clean snowmobiles are becoming more popular for use in areas where the environment needs to remain unpopulated. The areas range from the polar ice caps when conducting research to the Yellowstone National Park for recreational use. These environments are areas where biomes can be threatened by excessive hydrocarbon emissions. It is for this reason that these snowmobiles are becoming increasingly more in demand. According to the SAE, they emphasize that locations, such as the Greenland Ice Caps, absorb the chemicals emitted into the atmosphere (About SAE Clean Snowmobile Challenge, 2016). This is hazardous to the environment when it comes to pollutants. However, researchers are at the location and need to conduct research. For that reason, a cleaner and less emissive snowmobile is required.

Another place that continues to combat the hydrocarbons emitted by the snowmobiles is Yellowstone National Park. National Park Services have pointed out that some of the current snowmobiles in use have an omitted valve train. This absent valve train leads to an excessive emission of hydrocarbons, which pollutes the surrounding environment (Bishop, Burgard, Dalton, & Stedman, 2006). Since Yellowstone National Park is wide spread and is home to several wildlife, it is imperative that zero emission snowmobile be designed in order to not pollute the surrounding environment.

Customer Requirements

The customer requirements were derived based upon the scoring of each event as described in the rules provided by the competition committee. Shown in Figure 1 below is a layout of the scoring for each event. When determining which event should be considered as a demanded quality, the design team focused on the events solely pertaining to the snowmobile cost and performance.

Zero Emissions Class Event	Minimum Points for Minimum Performance	Maximum Points for Relative Performance in Event
Engineering Design Paper	5	100
Manufacturer's Suggested Retail Price (MSRP)	2.5	50
Oral Presentation	5	100
Weight	0	100
Range	5	100
Draw Bar Pull	5	100
Acceleration + Load Event	2.5	50
Objective Handling and Drivability	2.5	50
Subjective Handling	2.5	50
Cold Start	2.5	50
Static Display	0	50
Objective Noise	3.75	75
Subjective Noise		75
No-Maintenance Bonus		100

Figure 1: 2016 SAE Clean Snowmobile Challenge Event Scoring Rubric (International, 2015)

This meant that the design paper, presentation, display, and bonus was not considered. This left the design team with the following eight categories to consider:

1. MSRP
2. Weight
3. Range
4. Draw Bar Pull
5. Acceleration plus Load
6. Handling & Drivability
7. Cold Start
8. Noise

With these 8 categories, the corresponding demanded qualities were developed. They were each given a weight of importance according to the number of points given to each event. The weight included both the objective and subjective points if the event contained one or the other. Figure 2 shows the demanded qualities along with their weights.

Table 2: Customer Requirements for SAE Zero Emissions Clean Snowmobile

Weight/Importance	Demanded Quality
50.0	Low MSRP
100.0	High Range Value
100.0	Average Draw Bar Pull
150.0	Little Noise
100.0	Efficient Drivability & Handling
50.0	High Pulling Acceleration
50.0	Cold Start Quickly and Successfully
100.0	Light Snowmobile

Engineering Requirements

With the customer requirements generated, ways to measure each needed to be identified. Identification of each quality measurement also required the desired direction to take in terms of obtaining the best possible design. All of this information is summarized below.

Table 3: Engineering Requirements and Level of Improvement

Engineering Requirement	Direction of Improvement
Price of Sled ($/Sled)	Minimize
Distance Travelled (km)	Maximize
Pulling Force (kN)	Maximize
A-Weighted Sound Pressure Level (dB)	Target
Lap Completion Time (s)	Minimize
Braking Time for a Complete Stop (s)	Target
Time to Accelerate with Attached Load (s)	Minimize
Maximum Velocity (m/s)	Maximize
Time to Cold Start (s)	Minimize
Sled Idol Time After Cold Start (s)	Maximize
Weight of Snowmobile (kN)	Minimize

One thing that must be reminded when finding the optimal design according to the direction of improvement for each requirement is that several of them are correlated with one another. For instance, weight was shown to have both positive and negative correlations with multiple requirements. This was a factor that was taken into consideration when identifying the target/ limiting values.

Lastly, once the customer and engineering requirements were identified, a design matrix was created. The design matrix was used as a way to measure which engineering requirements needed to be addressed the most. It showed that distance travelled, lap completion time, and weight were the most impactful. For that reason, the design team chose to make modifications in the battery, motor, and controller of the snowmobile.

Competitive Analysis

As soon as the modifications were made and a final design was drafted, a competitive analysis was chosen in order to see how it compared. The competitors in the analysis were the previous winners in each category for the past five years. The competitors were ranked from 0 to 6 according to the results compared to the target values in Table 1. Figure 2 shows the trend for each competitor.

Competitive Analysis
(0=Worst, 5=Best)

IUPUI Zero Emissions Clean Snowmobile	2015 Competition Category Winners	2014 Competition Category Winners	2013 Competition Category Winners	2012 Competition Category Winners	2011 Competition Category Winners
0	1	5	4	2	3
4	3	2	0	1	5
2	1	0	3	4	5
1	0	3	5	2	4
2	4	1	0	5	3
0	4	2	1	3	5
5	5	0	5	5	5
3	0	2	4	1	5

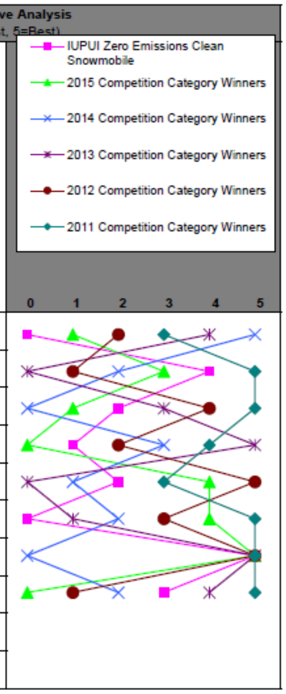


Figure 2: Competitor Analysis

The analysis tells us that the design chosen with the given targets yields a design that is similar to all of the other competitor designs. The design chosen may not have been the best in every category, but it shows that it is the best all round.

Design Considerations

Earlier in the paper, it was mentioned that modifications were made to the original stock in order to improve the design for two specific categories, more specifically, the motor and battery.

Motor Selection

The choice between an AC and DC motor is difficult. While the Warp9 DC motor has been used successfully in years past, the team decided to use an AC motor. The Electrical Engineering team has experience with AC systems and technology, while the Mechanical engineers assisted in installation and design.

Limiting factors

The controller available, a Curtis-1238, limited the power of the AC motor to 80V. While this combination would limit the torque of the snowmobile, it was decided that this could be used to our advantage in the range competition by being more efficient.

Efficiency

AC motors have been rated roughly ten per cent more efficient than the DC motor in some cases. For the competition, the AC motor should also allow a higher average speed useful in several events.

Weight

The AC motor is 50 pounds lighter than the Warp9 DC motor. The range will increase with a lighter snowmobile.

For the motor, the design team decided to go with an AC Motor. An AC Motor provides several advantages as well as disadvantages. These are outlined in the list below.

Advantages

1. Zero hydrocarbon emissions.
2. More reliable, maintenance free.
3. Easier to clean.
4. Longer run time for a given battery charge.
5. Longer driving range.

Disadvantages

1. Requires more battery in series.
2. More expensive conversion.

Gearing

Sprocket selection uses a 3:1 ratio so that the AC motor can run at 3,000 rev/min and allow for 20 mi/hr (32 mi/km) optimum efficiency. Figure 3 shows the gear selection using the Maximizer software.

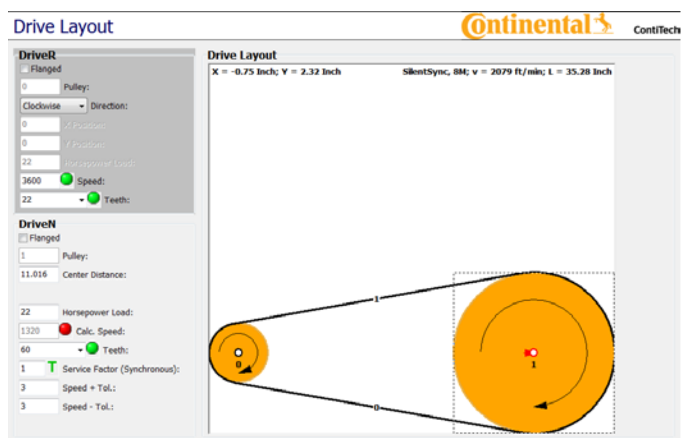


Figure 3: Using Continental Silent Sync Sprockets

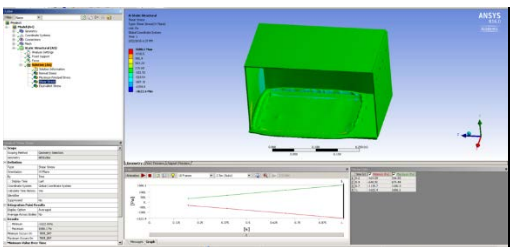
Battery Selection

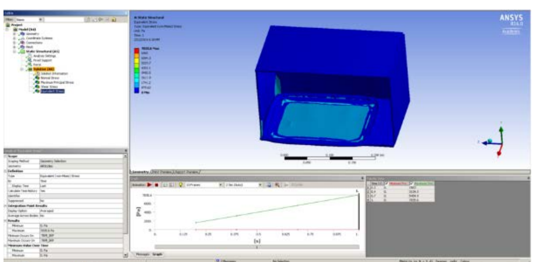
The batteries that will be used is Lithium Iron Phosphate (LiFePO4). The LiFePO4 batteries provided several advantages that are beneficial to the snowmobile. One advantage is the battery's longer life cycle. LiFePO4 batteries also offer a higher peak-power rating compared to other lithium ion batteries. This is a good compromise since the AC Motor is not expected to perform well in the draw bar pull compared to a DC Motor. With a higher peak-power rating, more load can be pulled (The Advantages/Diadvantages for LiFePo4 Batteries, 2011).

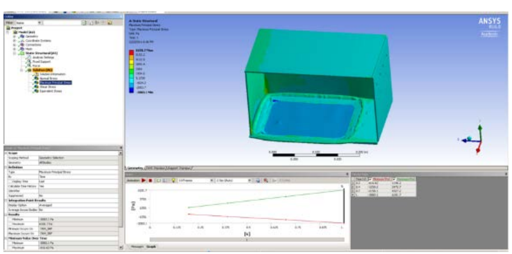
Our total battery energy is 4752 W-hr. When applying a safety factor for the battery of 20% we can expect to have a capacity of 3802 W-hr. Our calculations show that we will be able to achieve between 200 W-hr/mi to 300 W-hr/mi so the range our snowmobile should be able to go is between 10 to 15 miles depending on snow conditions.

The advantages of the AC in terms of longer run time on batteries and longer driving range are significant to our design. It is also worth noting again that range was a factor that needed to be maximized.

Battery Container







A general Static analysis on Ansys allowed a general overview of how the battery cells will impact the plastic. Initial results were showed sufficient strength.

Rider Comfort

In our design, we slightly change the position of the seat since we placed the three battery boxes under the seat. The space in our snowmobile is for the person with medium height, who will be comfortable to drive the snowmobile. The handlebars can be adjusted to accommodate other size drivers.

Conclusion

From design decisions that were chose, the SAE Zero Emission Clean Snowmobile is expected to perform well enough to establish a baseline of result for future comparison and analysis. The current battery and motor selection provides a great combination to perform well in the ranged events. It also provides enough power to be competitive in the events that require high power over a short amount of time. Ultimately, the designed snowmobile can be viewed as significant milestone for the future success of the team.

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Acknowledgments

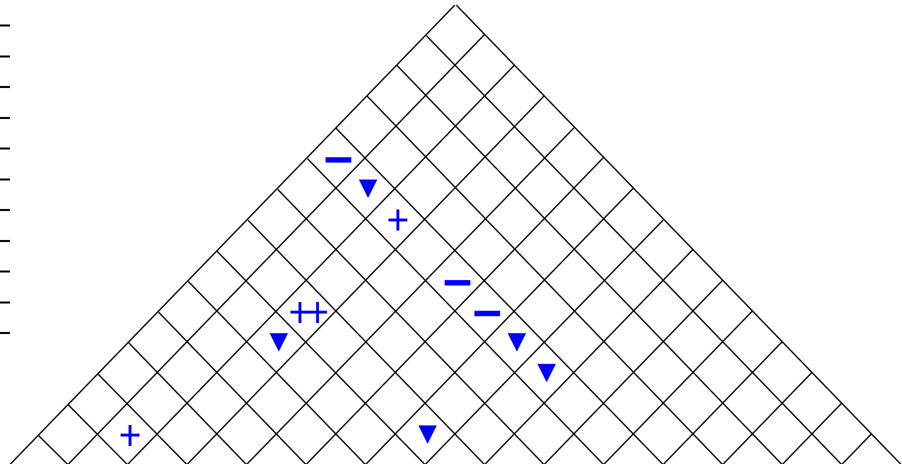
We acknowledge all the students of the 2015-2016 IUPUI design teams. Our sponsors were critical to our success, as well.

Title: SAE Zero Emissions Clean Snowmobile

Author: IUPUI SAE Snowmobile Club

Date: 2/19/2016

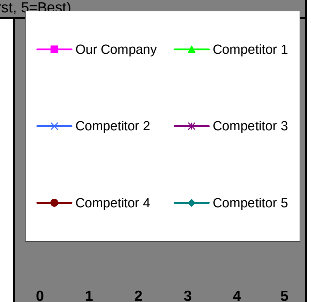
Notes:



Legend		
Θ	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
−	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
x	Objective Is To Hit Target	

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats") / Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	1 Price of Sled ($/Sled)	2 Distance Travelled (milest)	3 Pulling Force (lbf)	4 A-Weighted Sound Pressure Level (dB)	5 Lap Completion Time (s)	6 Braking Time for a Complete Stop (s)	7 Time to Accelerate with Attached Load (s)	8 Maximum Velocity (mph)	9 Time to Cold Start (s)	10 Sled Idol Time After Cold Start (s)	11 Weight of Snowmobile (lbf)	12	13	14	15	Our Company	Competitor 1	Competitor 2	Competitor 3	Competitor 4	Competitor 5
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▼	▲	▲	x	▼	x	▼	▲	▼	▲	▼										
1	9	7.1	50.0	Low MSRP	Θ										▲										
2	9	14.3	100.0	High Range Value		Θ						O			Θ										
3	9	14.3	100.0	Average Draw Bar Pull		Θ	Θ					▲			Θ										
4	9	21.4	150.0	Little Noise				Θ																	
5	9	14.3	100.0	Efficient Drivability & Handling					Θ	Θ					O										
6	9	7.1	50.0	High Pulling Acceleration		O	Θ				Θ	Θ			O										
7	9	7.1	50.0	Cold Start Quickly and Successfully									Θ	Θ											
8	9	14.3	100.0	Light Snowmobile			O		▲	O	O	O			Θ										
9																									
10																									

Competitive Analysis (0=Worst, 5=Best)



Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Target or Limit Value		20 Miles	300 lbf	0 dB	60 s	5 s	20 s	25 mph	20 s	300 s	650 lbf				
Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	5	5	10	7	6	3	7	8	8	5	9				
Max Relationship Value in Column	9	9	9	9	9	9	9	9	9	9	9				
Weight / Importance	64.3	278.6	235.7	192.9	142.9	171.4	107.1	164.3	64.3	64.3	457.1				
Relative Weight	3.3	14.3	12.1	9.9	7.4	8.8	5.5	8.5	3.3	3.3	23.5				